Madrid-to-JPL 50 kbits/s Wideband Error Statistics

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Detailed analysis of the results of wideband data tests conducted at 50 kbits/s in June 1971 between Madrid and the SFOF confirms the burst nature of the transmission errors.

Measured burst length depends critically on the definition of a burst. A typical burst length of 200 bits was determined for the error model and method of measurement employed. During good circuit conditions the block error rate varies directly with block length; however, this proportionality does not hold during poor circuit conditions. The average number of error bits in an error block holds reasonably constant even as the error rate changes several orders of magnitude.

I. Introduction

During the period June 8–14, 1971, a lengthy wideband data test was conducted between the SFOF Comm Terminal at JPL and the NASCOM Madrid Switch Center adjacent to DSS 61. The test, which was run at 50 kbits/s, had two objectives: (1) to determine the error rates of a circuit generally comparable to those expected to be used in support of MVM'73, and (2) to determine the statistical distribution of these errors.

An earlier report (Ref. 1) presented data on the first objective, i.e., the general error rates. This article provides information on the second objective, the fine-grained distribution of the errors.

II. Configuration

The complete test configuration is described in detail in the earlier report. The arrangement consisted of a full-duplex 50-kbit/s circuit between the SFOF Comm Terminal and the NASCOM Madrid Switch Center. The circuit was regenerated at the main NASCOM switch at the Goddard Space Flight Center. A communication satellite link was used between the United States and Spain. Test data consisted of the 2047-bit pseudo-random pattern generated by Fredricks Model 600 Test Sets (F600). The received data was normally accepted by an F600, synchronized, and the bit/block errors counted and recorded.

During two different four-hour periods, however, the receive line at JPL was diverted from the F600 and routed to the Simulation Center where the incoming bits were logged on magnetic tape by the 6050 computer. This special configuration, shown in Fig. 1, provided the raw data for the fine-grained error analysis.

The 6050 tapes were reduced by two 360/75 programs. The first program compared the recorded sequence against the known 2047 bit pseudo-random pattern, noting the distance between errors. The second program calculated various statistics from the distance-between-errors data.

During the processing of the twenty-five reels of 6050 raw data, it was determined that the information on thirteen of the reels could not be readily reduced for several reasons, including lack of knowledge of where the data stopped on each reel. These thirteen reels were subsequently discarded, since the remaining twelve sequences provided a very adequate sample (5.73×10^8 bits, about 3.17 h) distributed over several different times and line conditions.

III. Results

Table 1 depicts some statistical parameters for each of the sequences. The sequences have been divided into groups according to the bit error rate of each sequence.

Characteristics of the three groups are as follows:

Group	Bit error rate X of each sequence	Number of sequences	Proportion of the total
Green	$X < 10^{-5}$	6	48.7%
Amber	$10^{-5} < X < 10^{-4}$	5	42.2%
Red	$X > 10^{-4}$	1	9.1%

The three groups, in order, represent excellent, normal, and poor error performance.

Burst length, an important statistical quantity, was measured using the simplifying assumption that bursts are separated by at least n good bits. Credit for this simple method is given to the Bell Telephone System who has used it in arriving at some of their published data. The value of n, 400 in this case, was chosen empirically after examining a large number of data runs.

Table 1 shows the average burst length for each sequence. The longest burst, 13,636 bits, occurred in Sequence 11. The shortest burst, 17 bits, occurred in nearly every sequence and is caused by the data set scrambler, which causes three output bit errors to occur every time a line error occurs.

The block error rate is shown for three different block lengths: 1200, 2400, and 4800 bits. Lengths of 6 and 10 bits were also calculated but are not shown. At low bit error rates (green and amber groups) the block error rate is generally proportional to the block length, substantiating that the error burst is short compared to a block length. As the error rate worsens (red group) this relationship no longer holds.

Table 1 also shows values of K for the three block lengths. K represents the average number of error bits in each error block. Restated, K is the number of bad bits in each bad block. It is significant in that it indicates how badly typical blocks are mutilated. Surprisingly, K remains reasonably constant over all block sizes and color groups, even as the error rate shifts nearly two orders of magnitude and the burst length changes by nearly an order of magnitude.

The burst ratio column is the ratio of the good (error free) bits to the bad (error) bits *within* a burst. If there were 50% errors inside a burst (as you might imagine), this ratio would be 1.0. As indicated, the ratio is always well above 1.0, indicating that most of the bits within a burst are error-free. In the red group the ratio climbs to almost nine, leading to speculation that some different error-producing mechanism (other than impulse noise) must come into play when such substandard error rates are produced. Such a mechanism could be a general decrease in the S/N ratio to the point where the random noise peaks produce errors.

The last set of columns shows the quantity of various bit transitions experienced in each sequence. Using a model developed by D. Card, of the DSN Engineering and Operations Section, the circuit and its delivered bits, can be considered to always be in one of two states —burst or error-free. During the error-free state all bits are delivered without errors. During the burst state, some bits are delivered in error and some are error-free, as evidenced by the good/bad ratio discussed earlier. Each bit may thus be classified as one of three types:

0 An error-free bit occurring during a non-burst state. (This is the "normal" state which we would like all bits to occupy.)

1 An error bit occurring within a burst.

2 An error-free bit occurring within a burst.

One further note on the model: A burst always starts with an error and ends with an error. This permits a firm determination of the beginning and end of each burst and eliminates the spectre of "bursts" which contain no errors.

Using the above tags, a 0-to-0 (0–0) transition occurs between two bits, both of which are error-free and outside a burst. A 0-to-1 (0–1) transition marks the beginning of a burst and is ultimately followed by a 1-to-0 (1–0) transition at the end of the burst. The transition columns in Table 1 contain counts of each of the seven permissible types of transitions (0–2 and 2–0 transitions are not permissible since category 2 bits can only occur within a burst while 0 bits only occur outside a burst).

From the transition data presented, it is possible to construct the Card transition probability matrices shown in Table 2. These matrices depict, for each of the groups and the total, the probability of occurrence of each of the transitions. The bit types across the top represent the state of bit n and the types along the left show the state of the $n + 1$ bit. For instance, in the green group, the probability of a 1-to-2 transition is 0.500, whereas the probability of a 1-to-0 transition is 0.016. As earlier discussed, 0–2 and 2–0 transition are not permitted and are not shown in the matrix.

The matrices readily show many of the characteristics previously pointed out, the burst nature of the errors, good/bad ratio in a burst, etc.

Figure 2 is a plot of the distance between bit errors for each of the three groups. For example, for the green group there were 600 cases where bits in error were only one bit apart, i.e., they were adjacent. There were 300 cases where error bits were two bits apart, that is, there was one good bit between two error bits.

The curves all have an initial slope of $1/2^n$ up to a distance of 8–10 bits, indicating a complete burst condition where half the bits are in error and half are correct. Beyond the 8–10 bit distance the curves flatten and enter a random error region where most of the bits are good and only a few are in error. The peak at 17 bits distance is caused by the data set and is not a "natural" phenomenon.

As may be deduced from the curves (and seen in the raw data) most of the errors occur in the burst condition. The occasional random-type errors, however, generate "bursts" containing many good bits. These good bits, in turn, cause the good/bad bit ratio to climb.

The good/bad ratio (Table 1) should, therefore, be viewed with a wary eye. The values shown are true, but only for the model described and then only when the burst length is determined as previously discussed.

An alternate model has been devised which permits both burst and random errors. Future effort may be devoted to determining the parameters of this expanded model.

IV. Applicability to MVM '73

The circuit tests reported on herein were run at 50 kbits/s. The wideband network now being implemented to support MVM'73 will operate at 28.5 kbits/s. Performance at the lower rate can only be determined by measurement after the new network is installed. Nevertheless, the performance prediction for the lower rate as compared to the 50-kbits/s data presented herein is as follows:

Parameter	*Effect of decreasing rate from 50 to 28.5 kbits/s*
Bit error rate	No change
Burst length	Will decrease in proportion to rate decrease
Block error rate	Will increase in inverse proportion to rate decrease
K	Will decrease in proportion to rate decrease
Burst good/bad ratio	No change
Transition probabilities	No change

V. Conclusions

(1) The typical burst length (200± bits) is short compared to the present wideband block length (1200 bits).

(2) The number of bits in error per block in error (K) is reasonably constant over large changes in bit error rate.

(3) The idea that most of the bits in a burst are error-free must be tempered with the definition of what constitutes a burst. Most of the errors actually occur in tight groups. Within these groups the bits are nearly totally random.

(4) Most of the time the error rate is better than the average. In fact, this gets even more so as the sample interval is decreased.

Reference

1. McClure, J. P., "Ground Communications Facility 50-kbps Wideband Data Error Rate Test," in *The Deep Space Network Progress Report*, Technical Report 32-1526, Vol. VI, pp. 149–151. Jet Propulsion Laboratory, Pasadena, Calif., Dec. 15, 1971.

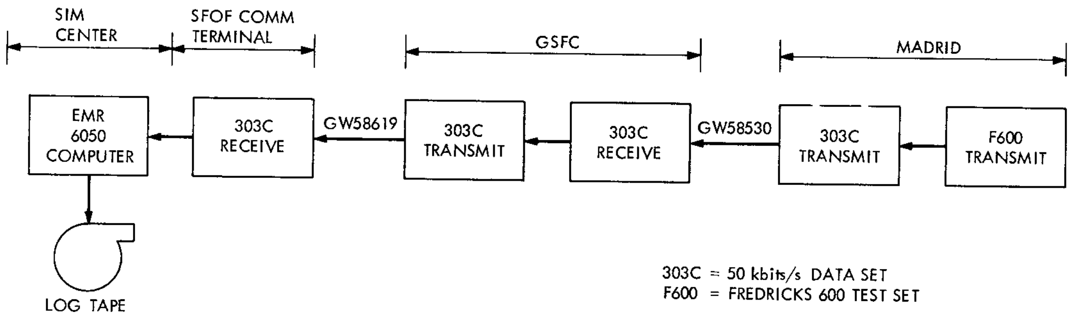

Fig. 1. 50-kbit/s wideband error statistics test configuration

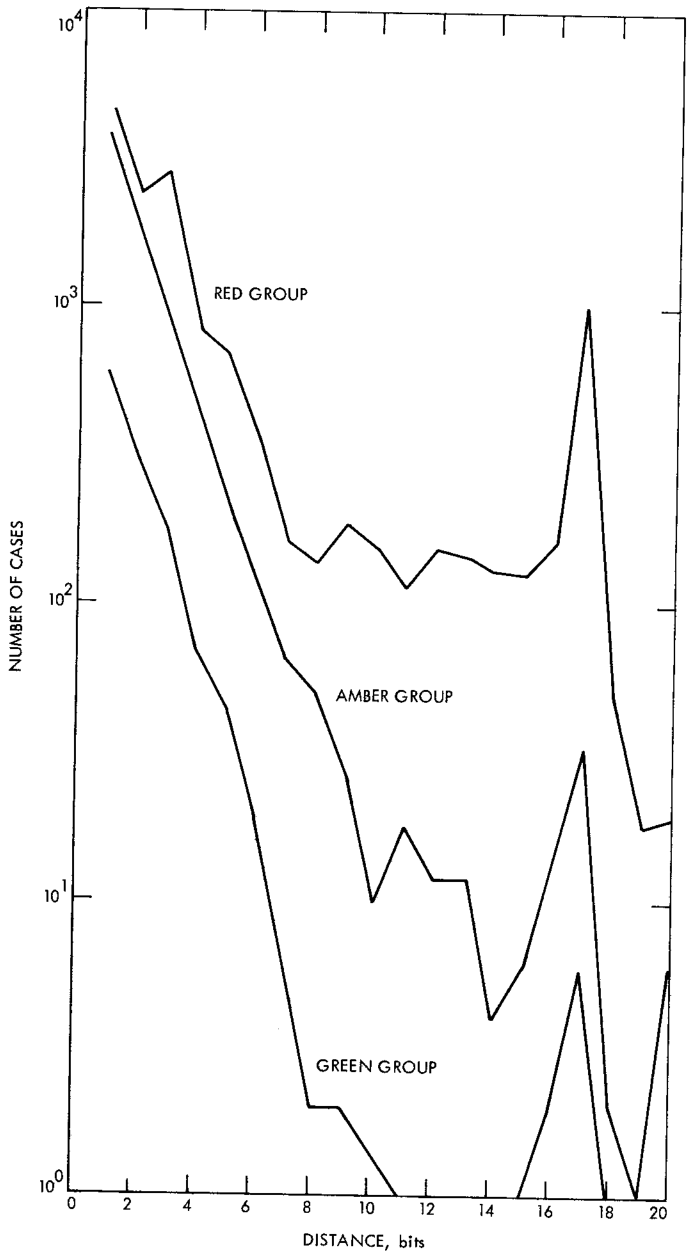

Fig. 2. Distance between bit errors

Group	Seqbence No.	Total bits	Bits in error	Bit error rate	Number of bursts	Average burst length	Block error rate		
							1200	2400	4800
Green	13	51451345	87	0.0000017	3	132.0	0.0000700	0.0001399	0.0002799
	14	46043171	260	0.0000056	4	151.5	0.0001043	0.0002085	0.0004170
	15	41468126	229	0.0000055	3	216.0	0.0001158	0.0001736	0.0003473
	16	44651211	177	0.0000040	3	178.0	0.0000806	0.0001613	0.0003225
	17	44301174	233	0.0000053	3	188.0	0.0001084	0.0002167	0.0003251
	18	51389935	248	0.0000048	4	171.2	0.0000934	0.0001868	0.0003736
Amber	3	39198003	2009	0.0000509	35	167.4	0.0012552	0.0022655	0.0041636
	6	42681997	1747	0.0000409	13	481.2	0.0004780	0.0007872	0.0014620
	8	62300445	1150	0.0000185	16	165.6	0.0003274	0.0005393	0.0010016
	19	54343756	1233	0.0000227	22	146.9	0.0005079	0.0009274	0.0018550
	20	43441434	1554	0.0000357	18	216.1	0.0005801	0.0009392	0.0017680
Red	11	52020411	15203	0.0002922	100	1513.9	0.0047982	0.0057670	0.0069207
Green total		279304962	1234	0.00000442	20	171.1	0.0000945	0.0001804	0.0003437
Amber total		241965635	7592	0.00003138	104	226.4	0.0005901	0.0010216	0.0019242
Red total		52020411	15203	0.0002922	100	1513.9	0.0047982	0.0057670	0.0069207
Grand total		573291008	24029	0.00004191	224	1037.6	0.0007305	0.0010424	0.0016076

Table 1. Error statistics

Average K			Burst good/bad ratio	Transitions						
1200	2400	4800		0-0	0-1	1-1	1-0	1-2	2-1	2-2
29.00	29.00	29.00	3.552	51450945	3	40	3	44	44	265
64.75	64.75	64.75	1.335	46042560	4	119	4	136	136	211
57.25	76.33	76.33	1.830	41467474	3	111	3	115	115	304
59.0	59.0	59.0	2.017	44650673	3	96	3	78	78	279
58.25	58.25	77.67	1.421	44300606	3	104	3	126	126	205
62.0	62.0	62.0	1.762	51389245	4	127	4	117	117	320
48.76	54.03	58.79	1.921	39192109	35	917	35	1047	1047	2812
102.71	124.71	134.31	2.581	42675727	13	859	13	874	874	3636
67.71	82.21	88.54	1.304	62297778	16	622	16	512	512	988
53.61	58.71	58.71	1.621	54340501	22	541	22	670	670	1329
74.0	91.41	97.13	1.503	43437525	18	759	18	777	777	1559
73.08	121.61	202.68	8.957	51868923	100	4695	100	10406	10406	125780
56.09	58.76	61.70	1.783	279301503	20	597	20	616	616	1584
63.80	73.71	78.27	1.871	241943640	104	3698	104	3880	3880	10324
73.08	121.61	202.68	8.957	51868923	100	4695	100	10406	10406	125780
68.85	96.50	125.15	6.350	573114066	224	8990	224	14902	14902	137688

Table 2. Card transition probability matrices

Green set	0	1	2
0	$1-(7.17 \times 10^{-8})$	0.016	—
1	7.17×10^{-8}	0.484	0.280
2	—	0.500	0.720
Amber set	**0**	**1**	**2**
0	$1-(4.30 \times 10^{-7})$	0.014	—
1	4.30×10^{-7}	0.481	0.273
2	—	0.505	0.727
Red set	**0**	**1**	**2**
0	$1-(1.93 \times 10^{-6})$	0.007	—
1	1.93×10^{-6}	0.309	0.076
2	—	0.684	0.924
Total set	**0**	**1**	**2**
0	$1-(3.91 \times 10^{-7})$	0.009	—
1	3.91×10^{-7}	0.373	0.098
2	—	0.618	0.902